Final Report

Development of a Computer Model for Management of Fuels, Human-Fire Interactions, and Wildland Fires in the Boreal Forest of Alaska

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Project Summary

Interior Alaska contains 140 million burnable acres and includes the largest National Parks and National Wildlife Refuges in the country. On average, wildland fires burn 1,000,000 acres in Interior Alaska each year and threaten the lives, property, and timber resources of Alaska's sparse but growing population. Wildland fires threaten human values, but they also are crucial for the maintenance of forest ecosystems. ***How do we manage wildland fire in Alaska for the mutual benefit of humans and natural ecosystems?*** Our project goal was to develop a computer-based, fire-management and planning model called Boreal ALFRESCO. The model would utilize physical, biological, and human thematic layers to simulate boreal ecosystem dynamics. Model outputs would include transient maps depicting the responses of vegetation cover and fuel accumulation under different scenarios of fire management and climate change. Our modeling had two objectives. First, to synthesize our existing knowledge about wildland fire in interior Alaska and reveal critical gaps in our knowledge. Second, once tested by field data, the model will provide a planning tool for land managers who are designing fire-management plans that can balance the needs of both natural ecosystems and of the humans living around and in them.

Earlier versions of the model revealed that we lack basic information concerning stand age and hazard-of-burning for different fuel types. We sampled approximately 3900 tree ages across a climatic gradient and developed hazard-of-burning functions for the major fuel types in interior Alaska. We estimated empirical hazard functions using empirical survival distribution functions, which represent the cumulative probability of survival for both coniferous and deciduous fuel types. Our results suggest that coniferous fuel types can be divided into two types – mixed (i.e., deciduous overstory) and pure stands. Conifers in mixed stands have a lower probability of burning than in pure stands for the first 70-100 yr. At 100-110 yr the mixed stand probabilities increase as the less flammable deciduous component senesces due to age, and begin to follow the hazard trends expressed by the pure stands.

Through the process of model development we identified three important information gaps: (1) understanding climatic controls on the interior Alaskan fire season, (2) the spatial pattern of fire severity and its effects on recolonization of burned areas, and (3) the relative importance of vegetation successional trajectories. Based on these perceived knowledge gaps we initiated exploratory research aimed at improving our understanding and informing Boreal ALFRESCO.

Records from the last 53 years reveal high variability in the annual area burned in Alaska and corresponding high variability in weather occurring at multiple spatial and temporal scales. We used multiple linear regression (MLR) to systematically explore the relationship between weather variables and the annual area burned in Alaska. In the MLR, seven explanatory variables and an interaction term collectively explain 79% of the variability in the natural logarithm of the number of hectares burned annually by

lightning-caused fires in Alaska from 1950-2003. Average June temperature alone explains one-third of the variability in the logarithm of annual area burned.

Fire severity plays an important role in determining the pattern and rate of post-fire colonization. From a landscape-level modeling perspective the spatial pattern of fire severity has direct implications for short- and long-term vegetation dynamics. We used remotely sensed data to quantify patterns of burn severity from 24 fires across three spatial resolutions. Several lines of evidence were explored. Collectively, our results strengthen the argument that, at a landscape level, differential flammability of vegetation exists in the Alaskan boreal forest, which strongly influences the observed patterns of spatial heterogeneity in burn severity.

Past research has identified two general models of post-fire secondary successional trajectory in interior Alaska – self replacement and species dominance relay (a.k.a., initial floristics). The relative importance of each trajectory at the landscape-scale is unknown. We built a multinomial logistic regression model explaining the relationship between classified vegetation type and solar insolation and elevation. The model correctly predicted over 75% of spruce distribution in the study area, which appears to be following a self-replacement trajectory.

Using stand age-height reconstructions we quantified the successional rates of two forest stands that appeared to be following the typical model of species dominance relay (a.k.a., initial floristics). Our results suggest longer time periods were required for black spruce to dominate the site than previously reported. Additionally, we collected a series of stand age data across definite forest borders. Using this age data and our results from the stand age reconstructions we tested several hypothesis regarding the trajectory of succession (species dominance relay versus self replacement). Our results suggested that 88% of the sampled borders did not follow a species dominance relay successional trajectory and that the majority of the study region was likely undergoing a self replacement trajectory following disturbance.

We developed a model (Boreal ALFRESCO) that simulates the response of subarctic and boreal vegetation in Alaska to changes in disturbance regime driven by both changes in climate and fire management. Boreal ALFRESCO currently operates at a landscape/regional-level with a 1 km^2 pixel resolution and an annual (growing season) time step; explicitly simulating the contagion process of fire spread and seed dispersal. The resultant simulation landscape is sampled to provide estimates of stand age distributions, spatial composition of ecosystems, and quantified estimates of fire regime (fire frequency and area burned).

We calibrated and validated Boreal ALFRESCO by reconstructing historical area burned in interior Alaska from 1859-2003 and comparing simulated stand age distributions with observed stand ages across a climatic gradient. Our results show that through external forcing of the area burned, climate influences stand-age distributions. However, the shape of the observed tree-age distribution is an intrinsic property of mixed species forests where post-fire species succession through differentially flammable vegetation types occurs.

We have applied the model to investigate the potential impacts of a changing fire regime due to climate forcings and/or changing suppression policy on the winter foraging habitat of caribou in interior Alaska. Model simulations indicate that changes in the frequency and extent of fire in interior Alaska may substantially impact the abundance and quality of winter habitat for caribou. Our results suggest that shorter fire frequencies (i.e., less time between recurring fires) on the winter range of the Nelchina Caribou Herd in eastern interior Alaska will result in large decreases of available winter habitat, relative to that currently available, in both the short- and long-term. Simulations with more frequent fires produced a relatively immature forest age structure, compared to that which currently exists, with few stands older than 100 yr. This age structure is at the lower limits of stand age classes preferred by caribou.

We also have applied the model to investigate fire-human interactions and develop a tool to explore the influence of wildfire suppression on short- and long-term vegetation dynamics. Simulations suggest that fire suppression is likely to increase the proportion of flammable vegetation on the landscape and reduce the long-term effectiveness of wildfire suppression.

Project Results

Our project achieved its proposed goals and produced a number of deliverables (both primary and secondary) (Table 1). Project product details are provided in the following subsections and in the accompanying CD.

Table 1. Table overview listing deliverables and their current status.

Product	Description	Primary/Secondary	Delivery Status
ArcView Shapefile	Shapefile of field plots	Primary	Completed – see enclosed CD
Database system (dBASE)	Database of all plot data linked to shapefile	Primary	Completed – see enclosed CD
Digital Photo Archive	Digital image archive from field plots	Secondary	Completed – see enclosed CD
Hazard of Burning Functions	Empirical hazard-of-burning functions	Primary	Completed – see final report
Boreal ALFRESCO Software & Documentation	Computer simulation model and documentation	Primary	Completed – see enclosed CD
Boreal ALFRESCO Simulation Maps	Selected project model results using Boreal ALFRESCO	Primary	In preparation – Winter 2005-2006 delivery
Refereed Journal Articles	Manuscripts developed from both the fieldwork and computer model development • Fire and Policy (Frontiers in Ecology) • Fire and Climate (Ecol. Appl.) • Caribou Habitat and Fire (Ecol. Appl.) • Succession Model (CJFR) • Burn Severity Patterns (IJWF) • Boreal ALFRESCO (Landscape Ecol.)	Primary/Secondary	• published 2003 – see enclosed CD • published 2005 – see enclosed CD • accepted 2005 • in preparation 2005 • in preparation 2005 • in preparation 2005
Final Report	Report describing project accomplishments	Primary	Completed

Stand Age Database

This project represents the first landscape-level study of stand-age distribution in interior Alaska. We sampled approximately 3900 black spruce, white spruce, birch, aspen, and tamarack trees across a climate gradient spanning cool and wet (green dots) to hot and dry (purple dots) growing-season conditions (Fig. 1). This first of its kind database is archived as an ArcView shapefile (Fig. 1) and an accompanying database system (dBASE) (Fig. 2).

Figure 1. Study area showing location of tree age samples (colored circles) along a climate gradient across interior Alaska. Inserts show subregion and plot sample (red dots) layout.

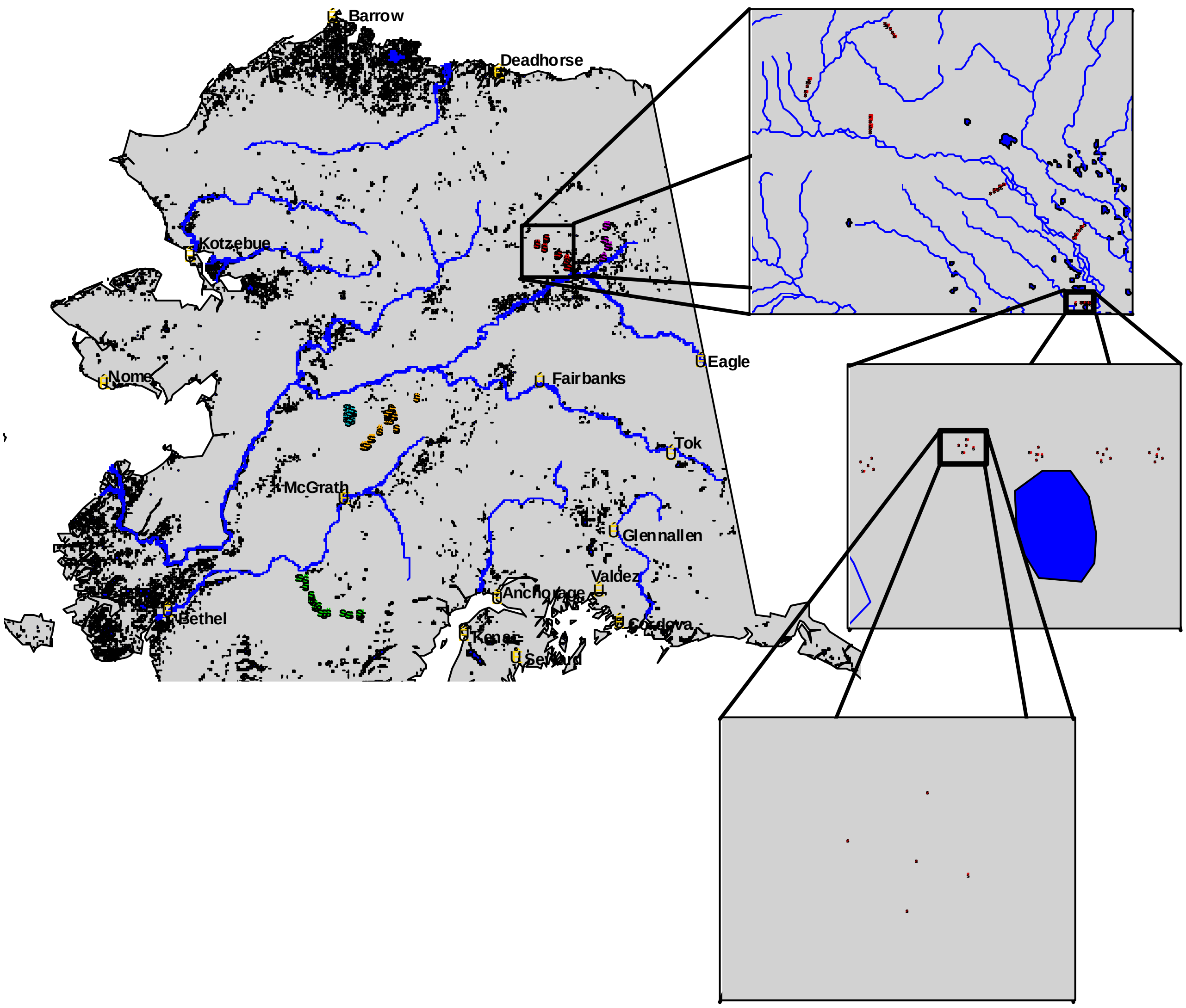
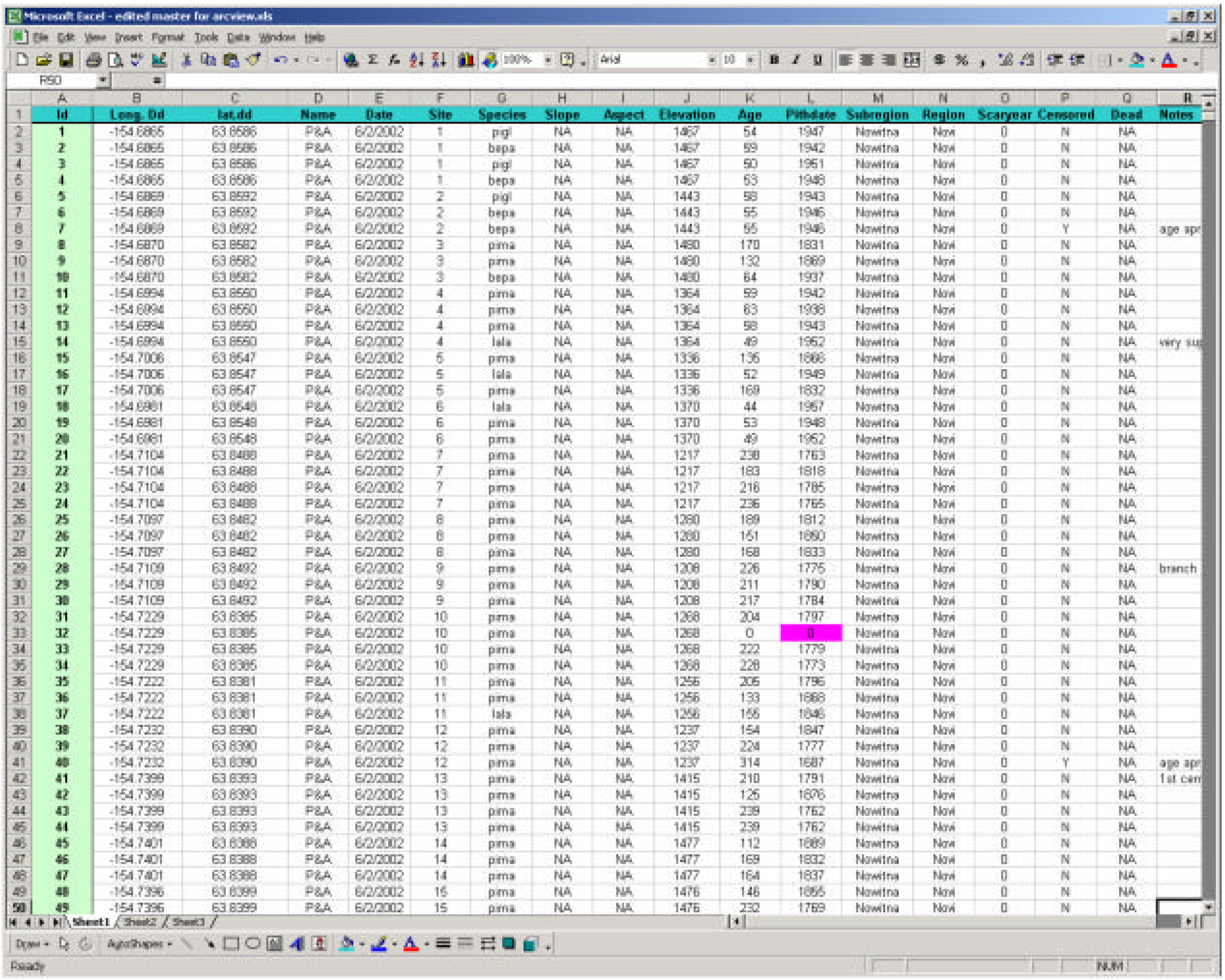


Figure 2. ArcView dBASE dataset of all sampled trees and data fields.



Id	Long. Dd	lat.dd	Name	Date	Site	Species	Slope	Aspect	Elevation	Age	Pithdate	Subregion	Region	Scaryear	Censored	Dead	Notes
1	-154.6865	63.8586	P&A	6/2/2002	1	pigl	NA	NA	1467	54	1947	Nowitna	Novi	0	N	NA	
2	-154.6865	63.8586	P&A	6/2/2002	1	bepa	NA	NA	1467	59	1942	Nowitna	Novi	0	N	NA	
3	-154.6865	63.8586	P&A	6/2/2002	1	pigl	NA	NA	1467	50	1951	Nowitna	Novi	0	N	NA	
4	-154.6865	63.8586	P&A	6/2/2002	1	bepa	NA	NA	1467	53	1948	Nowitna	Novi	0	N	NA	
5	-154.6869	63.8592	P&A	6/2/2002	2	pigl	NA	NA	1443	58	1943	Nowitna	Novi	0	N	NA	
6	-154.6869	63.8592	P&A	6/2/2002	2	bepa	NA	NA	1443	55	1946	Nowitna	Novi	0	N	NA	
7	-154.6869	63.8592	P&A	6/2/2002	2	bepa	NA	NA	1443	55	1946	Nowitna	Novi	0	Y	NA	age ap
8	-154.6870	63.8582	P&A	6/2/2002	3	pima	NA	NA	1480	170	1831	Nowitna	Novi	0	N	NA	
9	-154.6870	63.8582	P&A	6/2/2002	3	pima	NA	NA	1480	132	1869	Nowitna	Novi	0	N	NA	
10	-154.6870	63.8582	P&A	6/2/2002	3	bepa	NA	NA	1480	64	1937	Nowitna	Novi	0	N	NA	
11	-154.6994	63.8550	P&A	6/2/2002	4	pima	NA	NA	1364	59	1942	Nowitna	Novi	0	N	NA	
12	-154.6994	63.8550	P&A	6/2/2002	4	pima	NA	NA	1364	63	1938	Nowitna	Novi	0	N	NA	
13	-154.6994	63.8550	P&A	6/2/2002	4	pima	NA	NA	1364	58	1943	Nowitna	Novi	0	N	NA	
14	-154.6994	63.8550	P&A	6/2/2002	4	lala	NA	NA	1364	49	1952	Nowitna	Novi	0	N	NA	very su
15	-154.7006	63.8547	P&A	6/2/2002	5	pima	NA	NA	1336	136	1866	Nowitna	Novi	0	N	NA	
16	-154.7006	63.8547	P&A	6/2/2002	5	lala	NA	NA	1336	52	1949	Nowitna	Novi	0	N	NA	
17	-154.7006	63.8547	P&A	6/2/2002	5	pima	NA	NA	1336	169	1832	Nowitna	Novi	0	N	NA	
18	-154.6981	63.8548	P&A	6/2/2002	6	lala	NA	NA	1370	44	1957	Nowitna	Novi	0	N	NA	
19	-154.6981	63.8548	P&A	6/2/2002	6	pima	NA	NA	1370	53	1948	Nowitna	Novi	0	N	NA	
20	-154.6981	63.8548	P&A	6/2/2002	6	pima	NA	NA	1370	49	1952	Nowitna	Novi	0	N	NA	
21	-154.7104	63.8488	P&A	6/2/2002	7	pima	NA	NA	1217	238	1763	Nowitna	Novi	0	N	NA	
22	-154.7104	63.8488	P&A	6/2/2002	7	pima	NA	NA	1217	183	1818	Nowitna	Novi	0	N	NA	
23	-154.7104	63.8488	P&A	6/2/2002	7	pima	NA	NA	1217	216	1785	Nowitna	Novi	0	N	NA	
24	-154.7104	63.8488	P&A	6/2/2002	7	pima	NA	NA	1217	236	1765	Nowitna	Novi	0	N	NA	
25	-154.7097	63.8482	P&A	6/2/2002	8	pima	NA	NA	1280	189	1812	Nowitna	Novi	0	N	NA	
26	-154.7097	63.8482	P&A	6/2/2002	8	pima	NA	NA	1280	151	1850	Nowitna	Novi	0	N	NA	
27	-154.7097	63.8482	P&A	6/2/2002	8	pima	NA	NA	1280	168	1833	Nowitna	Novi	0	N	NA	
28	-154.7109	63.8492	P&A	6/2/2002	9	pima	NA	NA	1208	226	1775	Nowitna	Novi	0	N	NA	branch
29	-154.7109	63.8492	P&A	6/2/2002	9	pima	NA	NA	1208	211	1790	Nowitna	Novi	0	N	NA	
30	-154.7109	63.8492	P&A	6/2/2002	9	pima	NA	NA	1208	217	1784	Nowitna	Novi	0	N	NA	
31	-154.7229	63.8385	P&A	6/2/2002	10	pima	NA	NA	1268	204	1797	Nowitna	Novi	0	N	NA	
32	-154.7229	63.8385	P&A	6/2/2002	10	pima	NA	NA	1268	0	0	Nowitna	Novi	0	N	NA	
33	-154.7229	63.8385	P&A	6/2/2002	10	pima	NA	NA	1268	222	1779	Nowitna	Novi	0	N	NA	
34	-154.7229	63.8385	P&A	6/2/2002	10	pima	NA	NA	1268	228	1773	Nowitna	Novi	0	N	NA	
35	-154.7222	63.8381	P&A	6/2/2002	11	pima	NA	NA	1256	205	1796	Nowitna	Novi	0	N	NA	
36	-154.7222	63.8381	P&A	6/2/2002	11	pima	NA	NA	1256	133	1868	Nowitna	Novi	0	N	NA	
37	-154.7222	63.8381	P&A	6/2/2002	11	lala	NA	NA	1256	155	1846	Nowitna	Novi	0	N	NA	
38	-154.7232	63.8390	P&A	6/2/2002	12	pima	NA	NA	1237	154	1847	Nowitna	Novi	0	N	NA	
39	-154.7232	63.8390	P&A	6/2/2002	12	pima	NA	NA	1237	224	1777	Nowitna	Novi	0	N	NA	
40	-154.7232	63.8390	P&A	6/2/2002	12	pima	NA	NA	1237	314	1687	Nowitna	Novi	0	Y	NA	age apr
41	-154.7399	63.8393	P&A	6/2/2002	13	pima	NA	NA	1415	210	1791	Nowitna	Novi	0	N	NA	1st cen
42	-154.7399	63.8393	P&A	6/2/2002	13	pima	NA	NA	1415	125	1876	Nowitna	Novi	0	N	NA	
43	-154.7399	63.8393	P&A	6/2/2002	13	pima	NA	NA	1415	239	1762	Nowitna	Novi	0	N	NA	
44	-154.7399	63.8393	P&A	6/2/2002	13	pima	NA	NA	1415	239	1762	Nowitna	Novi	0	N	NA	
45	-154.7401	63.8388	P&A	6/2/2002	14	pima	NA	NA	1477	112	1889	Nowitna	Novi	0	N	NA	
46	-154.7401	63.8388	P&A	6/2/2002	14	pima	NA	NA	1477	169	1832	Nowitna	Novi	0	N	NA	
47	-154.7401	63.8388	P&A	6/2/2002	14	pima	NA	NA	1477	164	1837	Nowitna	Novi	0	N	NA	
48	-154.7396	63.8399	P&A	6/2/2002	15	pima	NA	NA	1476	146	1855	Nowitna	Novi	0	N	NA	
49	-154.7396	63.8399	P&A	6/2/2002	15	pima	NA	NA	1476	232	1769	Nowitna	Novi	0	N	NA	

Empirical Hazard-of-Burning Functions

Hazard of burning functions can be derived from time since last fire (TSLF) data under the assumption that fires are stand replacing. It is certainly the case that the majority of fires in interior Alaska are stand replacing; however there is a significant degree of heterogeneity with respect to burn severity and fires often contain unburned inclusions. The heterogeneity observed within fires can be partially attributed to differentially flammable vegetation. Despite this, at the landscape spatial scale where stands are considered at approximately a $1km^2$ spatial resolution, roughly 80% of the inter-annual variability in the logarithm of area burned can be explained by monthly weather and atmospheric teleconnection indices. This relegates the role of differentially flammable vegetation to some portion of the remaining 20% of the variability that is unexplained by weather and atmospheric teleconnection indices. Hence, differentially flammable vegetation plays a secondary role to climatic conditions when considering the inter-annual variability in area burned at a landscape scale.

Despite the dominant role of climate at the landscape scale, differences in flammability derived from TSLF data provide information about the behavior of fires at smaller spatial resolutions and also allow for refinement of the conceptual model relating fire and vegetation within the boreal forest of Alaska. Typically, a hazard of burning function is estimated through the use of an analytic probability distribution (e.g. the weibull or gamma distributions). Attempts to fit analytic distributions to the TSLF field data obtained during this project did not produce models with an acceptable goodness of fit. This is most likely due to a lack of stationarity in the underlying process that regulates fire-vegetation interactions in the boreal forest of interior Alaska. Given that climate is the primary driver of annual area burned, the lack of stationarity is not surprising. When analytic models fail to provide an adequate fit to the data, empirical methods are often useful.

The survival distribution function (SDF) represents the cumulative probability of survival. It equals 1 when trees are youngest (at age = 0) and it approaches 0 as we consider the oldest trees. In using this model, it is assumed that when a tree dies from fire, another tree replaces it. We calculated SDFs for both coniferous (*Picea mariana* and *Picea glauca*) and deciduous (*Populus tremuloides* and *Betula papyrifera*) forest types based on the trees sampled from three locations across interior Alaska. From the empirical SDFs, an empirical hazard function can be estimated. In this context, the hazard function can answer the question: “If a tree is 50 years old, what is the probability it is going to burn within the next decade?” Mathematically this can be formulated in the following way.

First, let ‘X’ represent the age of the tree at the time it dies due to fire. This variable ‘X’ can take on many values ranging from 1 to the age of the oldest tree. To calculate the conditional probability of fire in the time interval (50 years – 60 years) assuming that a tree survived to a certain age (x = 50), the following formula is used,

$$P(50 < X \le 60 \mid X > 50) = \frac{S_x(50) - S_x(60)}{S_x(50)} \qquad (1)$$

The left hand side of the equations basically says: What is the probability that a tree will die between the age of 50 and 60 (e.g. P(50<X<60)), if we assume that the tree is already fifty years old (e.g. | X > 50). The vertical bar denotes any information to be conditioned on. Any question regarding the data-based estimate of the conditional probability of fire in a given interval (e.g. within the next decade) can be answered solely in terms of the SDF as shown in the right hand side of Equation (1). The estimate is 'conditional' since we are using the fact that the tree has survived to a given age (i.e. 50 years in the above example), as opposed to asking the question: "If a tree is 1 year old, what is the probability it will die between the ages of 50 and 60?"

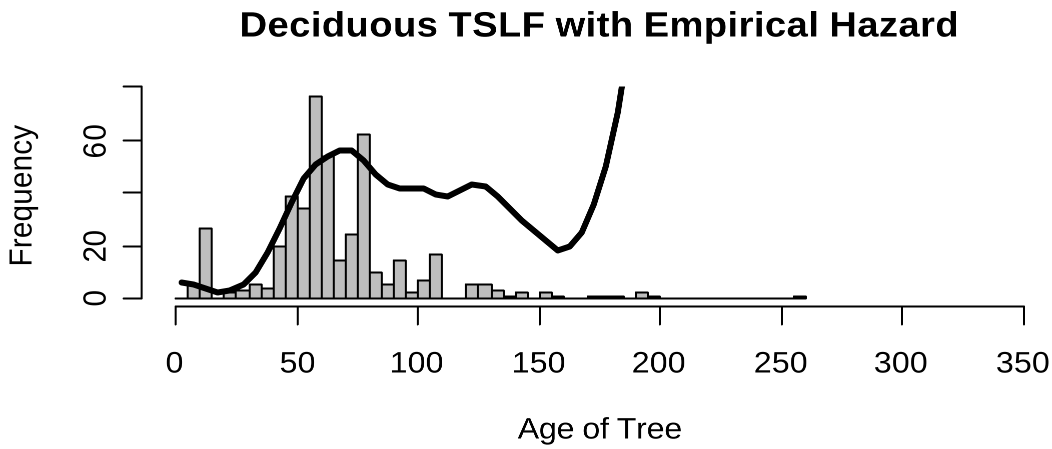
In general, for any interval and any tree age of interest, the empirical, data based conditional probability of fire can be estimated. Let 't' denote the length of the interval of interest (e.g. 10 in the above example) and let 'x' represent the specific age of interest (e.g. 50 in the above example). Note that 'x' is used to represent a specific age of a tree and 'X' is used to represent the variable 'age of the tree at the time it dies due to fire'. 'X' has a distribution associated with it whereas 'x' is a specific value from that distribution. Given this, the formula used to answer the question: "What is the probability that a tree of age 'x' will die from fire within the next 't' years?" is provided in Equation (2).

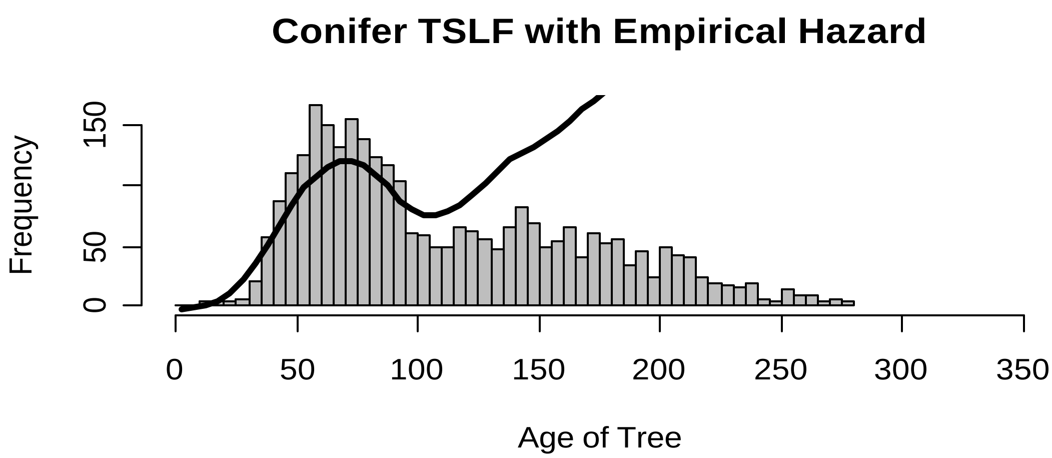
$$P(x < X \le x + t \mid X > x) = \frac{S_x(x) - S_x(x+t)}{S_x(x)} \qquad (2)$$

By examining various values of 'x' and 't' in Equation (2) we can compute and compare the empirical probability of burning as a function of tree age for both the deciduous and coniferous forest types.

One important consequences of the fact that climate signals drive the inter-annual variability in area burned is that the hazard of burning is not absolute and changes as a function of the current weather. Additionally, it is probable that different forest types respond to changes in weather differently. For example, a spruce stand may become flammable more quickly during a period of hot weather than a deciduous stand. Despite this, we can gain information about the differential flammabilities of deciduous and coniferous vegetation by looking at the hazard functions for time intervals that are longer than a year. The result yields information about the general properties of flammabilities that are most useful for relative comparisons between forest types. For this example we look at smoothed empirical hazard functions that were calculated for 5 year intervals (i.e. 't' = 5 in Equation 2). Figure 3 shows a comparison of the empirical hazard computed for both the coniferous and deciduous vegetation.

Figure 3. Histograms of tree age data with empirical hazard function. The empirical hazard functions were computed based on the probability of burning in a 5-year interval and then smoothed.





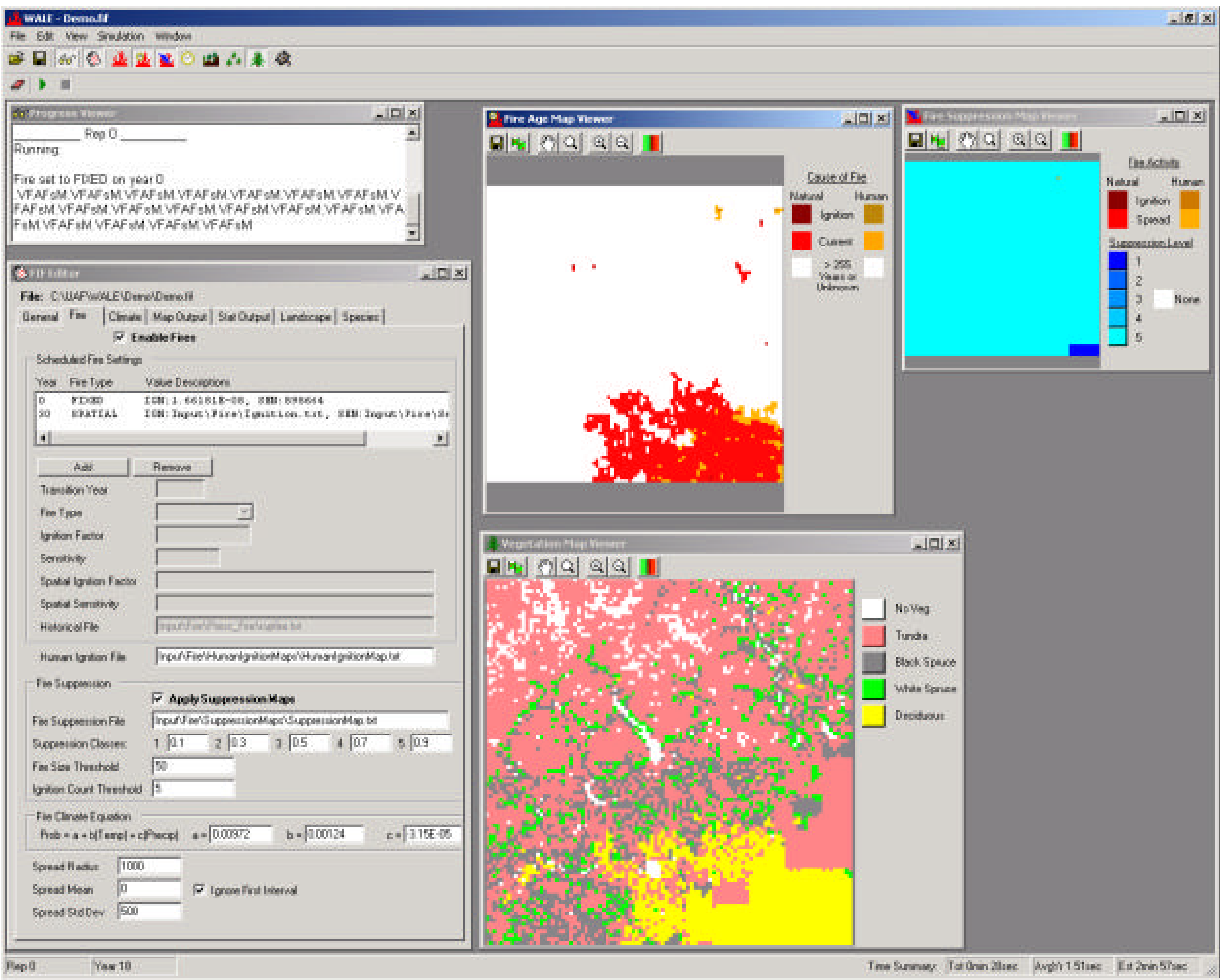
There are several interesting aspects to note when comparing the deciduous and coniferous hazard functions. First, it is important to note that each hazard curve is scaled to its respective histogram, so the comparison between the two is relative and not absolute. Second, for the first seventy years, both forest types behave roughly as one would expect with both hazards increasing. After seventy years, we see the hazard decrease for both forest types. For deciduous trees, this is what we would expect. As the canopy closes and the understory litter becomes more dominated by the deciduous litterfall, the hazard of burning should decrease. It is however unexpected to see a similar decline in the hazard for the conifers. The explanation is that these conifers are ‘hiding’ inside the relatively less flammable deciduous overstory. Further evidence for this interpretation is provided by the age where the hazard for the coniferous trees begins to increase again. This occurs at approximately 100 years. Roughly 90% of the deciduous trees sampled were less than 100 years old. This is about the TSLF where mixed forests shift dominance from deciduous trees to conifers. Many of the deciduous trees do not die from fire and as a consequence, the large spike observed at the end of the hazard curve for deciduous trees is a result of natural mortality, as opposed to fire.

In summary, for the purposes of analyzing Figure 3, coniferous forests can be divided into two types: mixed forest (i.e. deciduous overstory) and pure stands. The conifers in mixed forests exist underneath a relatively less flammable overstory and have a lower probability of burning than those conifers growing in pure stands. As deciduous dominated stands mature, they reach their maximum ability to resist fire. Based on Figure 3 this period lasts from about 70-100 years. After roughly 100 years have passed since the last fire, deciduous trees begin to die from non-fire related causes and the conifers that were once protected by the less flammable deciduous overstory now become exposed and the overall hazard for conifers increases. This occurs at roughly 100-110 years.

Boreal ALFRESCO Software, Documentation, and Results

The primary goal of this project was to develop the Boreal ALFRESCO software for use as a management tool to evaluate the short- and long-term response of the interior Alaskan landscape to different scenarios of environmental and anthropogenic change and/or fire management. The Boreal ALFRESCO software provides a user interface (Fig. 4) that allows managers to initiate, simulate, and analyze various current and future scenarios of interest.

Figure 4. Screen shot of the Boreal ALFRESCO software.



We have applied the model in two case studies to date. First, a study to develop a conceptual model to investigate fire-human interactions was conducted. Boreal ALFRESCO was used to explore the short- and long-term influence of wildfire suppression on future vegetation distribution and fire regime (Chapin et al. 2003 – *Frontiers in Ecology and the Environment*). Second, we applied the model to explore the potential influence of a changing fire frequency on winter habitat of the Nelchina Caribou Herd in eastcentral Alaska (Rupp et al. 2005 – Ecological Applications).

The final model results product is currently being addressed and will be completed in winter 2005-2006. Due to the record 6.7 million acre 2004 fire season and the ensuing National Interagency Burned Area Emergency Response Team assessment we were unable to complete specific project applications of Boreal ALFRESCO or receive adequate feedback from federal participants that attended a series of model development workshops. This work will be completed through an interagency working session in October 2005, informal meetings with key federal collaborators throughout the 2005-2006 winter, and direct collaboration with the technology transfer staff at Alaska Fire Service. This work will culminate with a formal workshop for all interested federal, state, and private fire/natural resource managers in March 2006.

Graduate Student Training

This project resulted in one Ph.D. project and two M.S. projects.

Paul Duffy, Ph.D. candidate, started his degree program in January 2001 and was an active participant in drafting our proposed research. Duffy developed the sampling scheme used to collect tree ages in the field. He has been responsible for developing the hazard-of-burning functions and has assisted PI Rupp in model development issues based upon our field studies. Duffy is scheduled to graduate in Spring 2006. His thesis covers issues related to climate-fire interactions (Duffy et al. 2005), spatial patterns of fire severity (Duffy et al. in preparation), and validating Boreal ALFRESCO (Duffy et al. in preparation).

Tom Kurkowski, M.S. candidate, started his degree program in January 2002 and successfully defended his thesis July 27, 2005 and will graduate August 15, 2005. Kurkowski developed a multinomial logistic regression model to predict the occurrence of vegetation type based on solar insolation and elevation. In addition, Tom used stand age-height reconstructions and stand boundary age information to infer successional trajectory across the landscape (Kurkowski et al. in preparation).

Mark Olson, M.S. Statistics, conducted his thesis project as part of our application work with the Nelchina Caribou Herd. Olson graduated in May 2004. Olson developed calibration and validation techniques to increase the prediction capability of Boreal ALFRESCO and extrapolated those techniques for stochastic simulation models in general. Olson completed the majority of simulation work for our application manuscript (Rupp et al. 2005).

Refereed Manuscript Abstracts

PLANNING FOR RESILIENCE: MODELING CHANGE IN HUMAN–FIRE INTERACTIONS IN THE ALASKAN BOREAL FOREST

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The development of policies that promote ecological, economic, and cultural sustainability requires collaboration between natural and social scientists. We present a modeling approach to facilitate this communication and illustrate its application to studies of wildfire in the interior of Alaska. We distill the essence of complex fire–vegetation interactions that occur in the real world into a simplified landscape model, and describe how equally complex fire–human interactions could be incorporated into a similar modeling framework. Simulations suggest that fire suppression is likely to increase the proportion of flammable vegetation on the landscape and reduce the long-term effectiveness of wildfire suppression. Simple models that test the consequences of assumptions help natural and social scientists to communicate objectively when exploring the long-term consequences of alternative policy scenarios.

Key words: ALFRESCO; fire regime; interior Alaska; landscape modeling; policy scenarios; spatially explicit; sustainability; wildfire suppression.

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IMPACTS OF LARGE-SCALE ATMOSPHERIC–OCEAN VARIABILITY ON ALASKAN FIRE SEASON SEVERITY

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Abstract. Fire is the keystone disturbance in the Alaskan boreal forest and is highly influenced by summer weather patterns. Records from the last 53 years reveal high variability in the annual area burned in Alaska and corresponding high variability in weather occurring at multiple spatial and temporal scales. Here we use multiple linear regression (MLR) to systematically explore the relationships between weather variables and the annual area burned in Alaska. Variation in the seasonality of the atmospheric circulation–fire linkage is addressed through an evaluation of both the East Pacific teleconnection field and a Pacific Decadal Oscillation index keyed to an annual fire index. In the MLR, seven explanatory variables and an interaction term collectively explain 79% of the variability in the natural logarithm of the number of hectares burned annually by lightning-caused fires in Alaska from 1950 to 2003. Average June temperature alone explains one-third of the variability in the logarithm of annual area burned. The results of this work suggest that the Pacific Decadal Oscillation and the East Pacific teleconnection indices can be useful in determining a priori an estimate of the number of hectares that will burn in an upcoming season. This information also provides insight into the link between ocean–atmosphere interactions and the fire disturbance regime in Alaska.

Key words: Alaska boreal forest; East Pacific teleconnection; ecological disturbance regimes; fire regimes; multiple linear regression; Pacific Decadal Oscillation; teleconnections.

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SIMULATING THE INFLUENCES OF VARIOUS FIRE REGIMES ON CARIBOU WINTER HABITAT

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Abstract. Caribou are an integral component of high latitude ecosystems and represent a major subsistence food source for many northern people. The availability and quality of winter habitat is critical to sustain these caribou populations. Caribou commonly use older spruce woodlands with adequate terrestrial lichen, a preferred winter forage, in the understory. Changes in climate and fire regime pose a significant threat to the long-term sustainability of this important winter habitat. Computer simulations performed with a spatially explicit vegetation succession model (ALFRESCO) indicate that changes in the frequency and extent of fire in interior Alaska may substantially impact the abundance and quality of winter habitat for caribou. We modeled four different fire scenarios and tracked the frequency, extent, and spatial distribution of the simulated fires and associated changes to vegetation composition and distribution. Our results suggest that shorter fire frequencies (i.e., less time between recurring fires) on the winter range of the Nelchina Caribou Herd in eastern interior Alaska will result in large decreases of available winter habitat, relative to that currently available, in both the short- and long-term. A 30% shortening of the fire frequency resulted in a 3.5-fold increase in the area burned annually and an associated 41% decrease in the amount of spruce-lichen forest found on the landscape. More importantly, simulations with more frequent fires produced a relatively immature forest age structure, compared to that which currently exists, with few stands older than 100 yr. This age structure is at the lower limits of stand age classes preferred by caribou from the Nelchina Herd. Projected changes in fire regime due to climate warming and/or additional prescribed burning could substantially alter the winter habitat of caribou in interior Alaska and lead to changes in winter range use and/or population dynamics.

Key words: ALFRESCO; Alaskan boreal forest; caribou; fire regime; global warming; landscape modeling; Rangifer tarandus; spatially explicit; spruce woodlands; succession.

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UPLAND BOREAL FOREST TOPOGRAPHIC-SUCCESSIONAL RELATIONSHIPS NEAR FAIRBANKS, ALASKA

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Abstract. Previous studies have suggested two general models of post-fire secondary succession in Interior Alaska. Self-replacement occurs where some constraint, usually fire frequency, environmental growing conditions, or available seed source, limits what species will dominate a site. Species-dominance relay occurs where a combination of deciduous and coniferous species can both establish, survive, and relay dominance through time. The relative importance of each of these successional trajectories in Interior Alaska is unknown. We built a multinomial logistic regression model explaining the relationship between classified vegetation type and solar insolation and elevation. Probabilities of supporting each species were calculated which allowed us to infer the most likely successional trajectory for the entire study area. The model correctly predicted approximately 78% of spruce distribution. The majority of the study area is following a self-replacement trajectory suggesting low probabilities of sites supporting both deciduous and spruce species. This has direct implications for modeling successional dynamics in Interior Alaska because the trajectory followed influences fire frequency, carbon storage, and regional climate feedbacks.

Key words: Alaska boreal forest; fire regimes; landscape modeling; multinomial logistic regression; self-replacement; solar insolation, vegetation succession.

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ANALYSIS OF ALASKAN FIRE SEVERITY PATTERNS USING NBR METRIC

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Abstract. Wildland fire is the dominant landscape-scale disturbance mechanism in the Alaskan boreal forest, and it strongly influences forest structure and function. Among the many attributes of fire, burn severity has specifically been related to post-fire successional trajectory, which in turn modifies carbon dynamics. In this work, we use remotely sensed data to quantify patterns of burn severity from 24 fires in the Alaskan boreal forest across three spatial resolutions, each differing by an order of magnitude. In this context, several lines of analysis are explored. First, the relationship between the mean burn severity and the area burned by a fire is modeled. Second, the relationship between the spatial correlation of burn severity and topography is characterized through an analysis of variograms. Third, we test the hypothesis that deciduous vegetation has greater variability in burn severity than other vegetation types. Finally, the relationship between burn severity and vegetation type is quantified using linear mixed models where variograms are used to explicitly account for the spatial correlation as a component of the error structure in the linear model. The results of these analyses show that: 1) average burn severity is directly proportional to the area of the fire, 2) topography significantly mediates the spatial correlation structure of burn severity, 3) we fail to reject the hypothesis that deciduous vegetation has greater variability in burn severity, and 4) There is a significant relationship between average burn severity and vegetation type that is mediated by topography. Collectively, these results strengthen the argument that, at a landscape scale, differential flammability of vegetation exists in the boreal forest of Alaska. Furthermore, the existence of differential flammability, mediated by topography/vegetation, strongly influences the observed patterns of spatial heterogeneity in burn severity. These simple models that characterize landscape-scale patterns of burn severity can inform or validate spatially explicit simulations that represent burn severity.

Key words: NBR; burn severity; variograms; spatial ANOVA; spatial resolution.

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RECONSTRUCTION OF HISTORICAL AREA BURNED IN ALASKA FROM 1859-2003: IMPLICATIONS FOR FORECAST CLIMATE CHANGE

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Abstract. The boreal forest covers roughly 1.37 x10^9 hectares and contains approximately 30% of the world's reactive soil carbon, an amount similar to that held in the atmosphere. The observed sensitivity of high latitude climate to global change makes it likely that the forecast warming over the next several decades will modify the fluxes associated with the large pool of high latitude carbon. In the Alaskan boreal forest, carbon flux initiated by wildland fire has the potential to react strongly to changes in climate. Recent statistical modeling has shown that for the period 1950-2003 roughly 80% of the interannual variability in the logarithm of area burned in Alaska can be explained by monthly weather and teleconnection indices. Here we use a modified version of this statistical model coupled with historical climatic and area burned data to produce a backcast of annual area burned in Alaska for the period 1859-2003. This backcast is used in conjunction with the historical record to calibrate a spatially-explicit cellular automata model (ALFRESCO) that simulates fire and successional dynamics across the landscape of interior Alaska. Output from ALFRESCO is analyzed using an ensemble approach and the simulated stand age distributions are compared to observed stand ages from three sites across interior Alaska. We test the hypothesis that the mean and variability of stand-ages are both significantly influenced by climate-initiated fire disturbance. Our results show that through external forcing of the area burned, climate influences stand-age distributions. However, the shape of the observed tree-age distribution is an intrinsic property of mixed species forests where post-fire species succession through differentially flammable vegetation types occurs. This work implies that stand ages and hence carbon pools within the boreal forest are sensitive to changes in climate. Furthermore, this work suggests that climatically driven changes in the fire regime can fundamentally alter the structure and function of the boreal forest.

Key words; Alaska boreal forest; ecological disturbance regimes; teleconnections; fire regime; fire reconstruction.

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